Citation for published version:
Voinescu, A, Babe-Bolyai University Icahn School of Medicine at Mount Sinai & Victor Babes University of Medicine and Pharmacy, Timisoara 2017, 'Virtual-reality-based attention assessment of ADHD: ClinicaVR: Classroom-CPT versus a traditional continuous performance test', *Child Neuropsychology*, vol. 23, no. 6, pp. 692-712. https://doi.org/10.1080/09297049.2016.1186617

DOI:
10.1080/09297049.2016.1186617

Publication date:
2017

Document Version
Peer reviewed version

Link to publication

This is an Accepted Manuscript of an article published by Taylor & Francis in Child Neuropsychology on 3 June 2016, available online: http://www.tandfonline.com/doi/full/10.1080/09297049.2016.1186617

University of Bath

Alternative formats
If you require this document in an alternative format, please contact:
openaccess@bath.ac.uk

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

Take down policy
If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Download date: 05. May. 2023

Neguț, A., Jurma, A. M., & David, D. (2017). Virtual-reality-based attention assessment of ADHD: ClinicaVR: Classroom-CPT versus a traditional continuous performance test. *Child Neuropsychology*, *23*(6), 692-712. doi:10.1080/09297049.2016.1186617

Virtual reality-based attention assessment in comparison with computerized assessment in ADHD: ClinicaVR: Classroom-CPT versus an analogue Continuous Performance Test

Alexandra Neguț, Anda Maria Jurma, and Daniel David

Alexandra Neguț, Evidence-based Assessment and Psychological Interventions Doctoral School; The International Institute for the Advanced Studies of Psychotherapy and Applied Mental Health, Babeș-Bolyai University, No. 37, Republicii Street 400015, Cluj-Napoca, Cluj, Romania. Telephone number: 0264434141, e-mail address: alexandra_negut@yahoo.com

Anda Maria Jurma, Neuroscience Department, Victor Babeș University of Medicine and Pharmacy, No. 7 Corbului Street 300239, Timișoara, Timiș, Romania. Telephone number: 0256494434, e-mail address: andamaria.jurma@gmail.com

Daniel David, Department of Clinical Psychology and Psychotherapy , Babeș-Bolyai University, No. 37 Republicii Street 400015, Cluj-Napoca, Cluj, Romania; Icahn School of Medicine at Mount Sinai, New York. Telephone number: 0264434141, e-mail address: danieldavid@psychology.ro

Correspondence concerning this article should be addressed to: Evidence-based Assessment and Psychological Interventions Doctoral School; The International Institute for the Advanced Studies of Psychotherapy and Applied Mental Health, Babeș-Bolyai University, No.

37, Republicii Street 400015, Cluj-Napoca, Cluj, Romania. Telephone number: 0264434141, e-mail address: alexandra_negut@yahoo.com

Acknowledgement

"This work was possible due to the financial support of the Sectorial Operational Program for Human Resources Development 2007-2013, co-financed by the European Social Fund, under the project number POSDRU/159/1.5/S/132400 with the title Young successful researchers – professional development in an international and interdisciplinary environment."

Virtual reality-based attention assessment in comparison with computerized assessment in ADHD: ClinicaVR: Classroom-CPT versus an analogue Continuous Performance Test

Abstract

Virtual reality-based assessment may be an alternative for classical or computerized neuropsychological assessment with increased ecological validity. ClinicaVR: Classroom-CPT is a neuropsychological test embedded in virtual reality and designed to assess attention deficits in children with ADHD or other conditions associated with impaired attention. In the present study we aimed to (1) investigate the diagnostic validity of ClinicaVR: Classroom-CPT in comparison to an analogue Continuous Performance Test (CPT), (2) explore the task difficulty of ClinicaVR: Classroom-CPT, (3) to address the effect of distractors on performance of ADHD participants and healthy controls, and (4) to compare the two measures on cognitive absorption. Thirty-three children diagnosed with ADHD and 42 healthy children, aged between 7 and 13 years old, participated in the study and were tested on cor an analogue CPT, plus several cognitive measures and an adapted version of the Cognitive Absorption Scale. Mixed MANCOVA revealed that ADHD children performed worse on correct responses had more commissions and omissions errors, and slower reaction time to targets than controls. Next, results showed significant differences between performance in the virtual environment and the computerized one with longer reaction time in virtual reality. Data analysis pointed out the negative influence of auditory distractors on attention performance in case of children with ADHD, but not for healthy participants. Finally, the two measures did not differ on cognitive absorption perceived by the children.

Keywords: virtual reality, ADHD, validity, neuropsychological assessment, CPT

Virtual reality-based attention assessment in comparison with computerized assessment in ADHD: ClinicaVR: Classroom-CPT versus an analogue Continuous Performance Test

Inattention and /or hyperactivity-impulsivity symptom dimensions are essential features of attention deficit-hyperactivity disorder (ADHD), a developmental disorder that affects approximately 5 % of children worldwide (American Psychiatric Association, 2013). ADHD is currently diagnosed by clinical interview and a variety of parent or outcomes (Barkley, 2006; Gualtieri & Johnson, 2005). Although they are critical to a valid assessment, they have limited predictive validity and are based on a subjective opinion (Lange et al., 2014). Neuropsychological tests may increase the effectiveness of the assessment of ADHD (Gualtieri & Johnson, 2005; Losier, McGrath, & Klein, 1996) as they target specific cognitive mechanisms that underlie the attention deficit and offers directions for individual interventions (Lange et al., 2014).

In neuropsychological assessment, ecological validity describes the degree in which a psychological test offers results similar to those expressed in real life (Chaytor & Schmitter-Edgecombe, 2003; Wasserman & Bracken, 2003). A red flag was raised by studies that attempted to investigate the ecological validity of paper-and-pencil neuropsychological tests in clinical (Chaytor & Schmitter-Edgecombe, 2003; Chaytor, Schmitter-Edgecombe, & Burr, 2006) and in healthy populations (Spooner & Pachana, 2006; Van der Elst, Van Boxtel, Van Breukelen, & Jolles, 2008), as they revealed a low to moderate level of ecological validity in predicting real life functioning. In the attempt to overcome this drawback, new tests with potential increased ecological validity have been designed. Some simulate daily cognitive tasks (Robertson, Ward, Ridgeway, & Nimmo-Smith, 1996; Wilson, Alderman, Burgess, Emslie, & Evans, 1996; Wilson,

Cockburn, & Baddeley, 1985), while others use virtual reality systems[1] for the assessment of cognitive processes (Matheis et al., 2007; Parsons & Courtney, 2014; Rand, Katz, Shahar, Kizony, & Weiss, 2005; Siemerkus, Irle, Schmidt-Samoa, Dechent, & Weniger, 2012).

Recent narrative (Bohil et al., 2011), systematic (Parsey & Schmitter-Edgecombe, 2013) and meta-analytical studies (Neguț, Matu, Sava, & David, 2016a; Neguț, Matu, Sava, & David, 2016b) have pointed out that virtual reality-based neuropsychological assessment might provide the ecological assessment associated with an increased level of task difficulty. Also, results have shown that virtual reality-based measures can be used for neuropsychological assessment of cognitive processes, such as executive functions, memory, visouospatial analysis or everyday functioning (Bohil et al., 2011; Neguț et al., 2016b; Parsey & Schmitter-Edgecombe, 2013) and that they discriminate between healthy and cognitive impaired patients (Neguț et al., 2016b).

One of the most used measure of sustained vigilance, attention and impulsivity is the Continuous Performance Test (CPT)[2] (Gualtieri & Johnson, 2005; Losier et al., 1996). Most CPT tests follow the original paradigm described by Rosvolt, Mirsky, Sarason, Bransome, & Beck (1956). The outcomes of interest for attention assessment with CPTs are total correct responses,

[1] Virtual reality-based assessment consists of a certain amount of stimuli delivered to the subjects in a highly systematic and controlled virtual environment (Bohil, Alicea, & Biocca, 2011) via a human-computer interface facilitated by computers, as well as via head-mounted displays (HMDs), trackers, headphones, data gloves or joysticks (Gamberini, 2000; Ku et al., 2003; Schultheis, Himelstein, & Rizzo, 2002). These devices generate a 3D environment that resembles the real world using advanced graphics and means of interaction.

[2] Depending on the cortical mechanisms of sustained attention (Sergeant, 2003) two main CPT tasks exist: the vigilance (activation mechanism) and the arousal tasks (arousal mechanism) (Servera & Cardo, 2006). In vigilance CPTs (known as X- or AX- types), participants are instructed to respond to target items while ignoring non-target items over longer periods of time (Rosvold, Mirsky, Sarason, Bransome, & Beck, 1956) and the subject has to respond correctly to target stimuli and inhibit responses to non-target stimuli. In inhibition CPTs described as non- X tasks participants are asked to respond to non-target items and to ignore the target items (Conners, Epstein, Angold, & & Klaric, 2003; M. Servera & Cardo, 2006).

errors of commission, errors of omission, and the mean reaction time[3] (Barkley, Grodzinsky, & DuPaul, 1992; Conners et al., 2003; Epstein et al., 2003; Frazier, Demaree, & Youngstrom, 2004; Losier et al., 1996; M. Servera & Cardo, 2006). Several types of CPT are used in research. Some integrate one sensorial modality (Conners, 1995; Servera & Llabrés, 2004), while others integrate both sensory and auditory modalities (Leark, Greenberg, Kindschi, Dupuy, & Hughes, 2007; Sandford & Turner, 1995). This high heterogeneity in versions of CPT might complicate decisions upon its utility in ADHD assessment (Berger & Cassuto, 2014; Epstein et al., 2003; Grodzinsky & Barkley, 1999; Preston, Fennell, & Bussing, 2005; Riccio & Reynolds, 2001).

In light of the recent controversies related to the level of ecological validity of traditional neuropsychological assessment (Bohil et al., 2011; Chaytor & Schmitter-Edgecombe, 2003; Parsey & Schmitter-Edgecombe, 2013; Spooner & Pachana, 2006; Van der Elst et al., 2008) one might assume that CPTs fail to provide measures of the degree in which children with ADHD perform in real life because the assessment context and cognitive tasks are far less realistic compared to real life challenges, like a school setting. Subsequently, as recomended (Barkley, 1991; Díaz-Orueta et al., 2014; Nigg, Hinshaw, & Halperin, 1996; Rizzo et al., 2000) other attention measures with increased ecological validity that target attention processes were developed. They consist of a virtual scenario that replicates a real classroom environment in which the child is immersed and has to perform a traditional CPT-based task (Iriarte et al., 2012; Rizzo et al., 2006).

[3]Total correct responses reflect the number of cases in which the participant correctly responds to target items; Commission errors occur when the participant responds to non-target items; Omission errors occur when the participant fails to respond to target items; Mean reaction time reflects the participant's average hit reaction time expressed in milliseconds or seconds

ClinicaVR: Classroom-CPT also known as Virtual Classroom (Rizzo et al., 2006) developed by Digital MediaWorks Inc. (http://web.dmw.ca/), is an AX- type CPT embedded in virtual reality designed to assess attention deficits in children with conditions associated with impaired attention like ADHD. Most studies that have investigated the diagnostic validity of ClinicaVR: Classroom-CPT by comparing attention performance of children with ADHD and healthy controls show that children with ADHD have impaired attention processes (Bioulac et al., 2012; Parsons, Bowerly, Buckwalter, & Rizzo, 2007; Pollak et al., 2009). However, less consent is available when it comes to specific ClinicaVR: Classroom-CPT outcomes that best discriminate between healthy and ADHD participants (Adams, Finn, Moes, Flannery, & Rizzo, 2009; Pollak et al., 2009). This might be due to the fact that some studies are underpowered and use different types of CPTs that might impact the generalization of the results. Also, only two studies provided data upon the classification accuracy of the Virtual Classroom compared to a CPT (Adams et al., 2009; Pollak et al., 2009). Both papers seem to indicate that Virtual Classroom classifies better ADHD participants than the CPT. As stated earlier, all these results point out the potential benefits of the ClinicaVR: Classroom-CPT over a traditional CPT. However, there is still need to conduct studies with increased statistical power that target the diagnostic accuracy of the ClinicaVR: Classroom-CPT compared to a CPT.

Another important issue in virtual reality-based assessment is distractors' effect on performance. The negative effect of distractors over cognitive performance is well documented in the literature (Areces, Rodríguez, García, Cueli, & González-Castro, 2016; Díaz-Orueta et al., 2014; Erez, Weiss, Kizony, & Rand, 2013; Iriarte et al., 2012; Ku et al., 2003; Rand, Basha-Abu Rukan , Weiss, & Katz, 2009; Rand, Katz, & Weiss, 2007). The use of distractors can enhance the ecological validity by maximizing the similarities between the real world and virtual

environment. For instance, in the ClinicaVR: Classroom-CPT three types of distractors are used: auditory (e. g. bus noise, door knocking, footsteps noise, and school bell ringing), visual (paper airplane thrown by a colleague, teacher looking at her watch) and mixed distractors (e. g. person walking into the classroom with hall sound when opened). In turn, the complexity and difficulty of the task increase due to the presence of distractors. This assumption is supported by data that points out poorer attention performance of children with ADHD when assessed in Virtual Classroom with distractors (Adams et al., 2009; Bioulac et al., 2012; Rizzo et al., 2000). However, the potential influence of distractors over CPTs parameters is not well documented in the literature and conventional CPTs do not include distractors (Uno et al., 2006) despite the fact that adding visual or auditory distractors seems to improve the utility of the CPT in ADHD diagnosis (Berger & Cassuto, 2014; Uno et al., 2006). To our knowledge the current study is the first one that aims to investigate differences in performance measured either with the ClinicaVR: Classroom-CPT and an analogue AX- type CPT under the influence of auditory distractors in case of children with ADHD and healthy controls. This allows us to directly investigate the influence of distractors on the task difficulty of ClinicaVR: Classroom-CPT and an analogue AX- type CPT and to check whether adding distractors has a greater impact on the discriminant validity of the measures.

In virtual reality research few studies have also focused on other subjective variables like fun or enjoyment (Pollak et al., 2009; Yalon-Chamovitz & Weiss, 2008). Therefore, in the current research we chose to on perceived level of cognitive absorption as a measure of software involvement that describes one's perceived level of experience, acceptance and enjoyment of new software, like motivation and beliefs about technology (Agarwal & Karahanna, 2000). Studies that focused on comparisons between virtual reality and other computer devices did not

pay attention to this potential relevant variable, it seems reasonable to investigate how the participants rate both measures and to check if any differences on cognitive absorption emerge. Previous research has shown that cognitive absorption correlates positively with the intention to use the software/technology devices in the future (Agarwal & Karahanna, 2000).

Based on findings from the literature (Bioulac et al., 2012; Neguț et al., 2016a; Neguț et al., 2016b; Nolin et al., 2016; Parsey & Schmitter-Edgecombe, 2013), we propose that neuropsychological testing using ClinicaVR: Classroom-CPT has a better ecological validity than an analogue AX- type CPT. In addition, we propose that it has an increased task difficulty associated with poorer performance in the ClinicaVR: Classroom-CPT. In turn, classical tests may underestimate the everyday performance on attention tasks translated into better performance on these traditional measures. Finally, the aims of the current study are to (1) investigate the discriminant validity of ClinicaVR: Classroom-CPT in attention assessment by comparing performance of children with ADHD with healthy controls[4], (2) explore the task difficulty of virtual reality-based measures by comparing attention performance obtained with a virtual reality-based measure and an analogue AX- type CPT, (3) to address the effect of auditory distractors on performance of ADHD participants and healthy controls, and (4) to compare the two measures on cognitive absorption.

Method

Participants

[4] Diagnostic validity is part of a criterion-related source of validity and is usually established by comparing two contrasted groups on outcomes of interest. In this case, diagnostic validity is established by comparing the performance of ADHD children with healthy controls (Wasserman & Bracken, 2003).

Forty-five boys and thirty girls aged between 7 and 13 years old (m = 9.49, SD = 1.67) participated in the study. There were differences on age between the two groups $t(55)=3.56$, $p < .001$ (mean age of the control group = 8.9 vs. mean age of ADHD group = 10.24). In the ADHD sample, 33.3 % of children (11 children) had comorbidities such as conduct disorder (8 children), learning disorder (2 children), and adjustment disorder (one child). According to parental report and medical records 69.7 % were on medication at the day of testing. Medication included stimulant drugs (i.e. methylphenidate in 30.43 % of children), non-stimulant drugs (i.e. atomoxetine in 34.78 % participants), and other drugs (e.g. typical and atypical neuroleptics, mood stabilizers 34.78 %). Of the ADHD children that were taking medication, 47.82% were on single agent medication and 52.17% were taking combined medication. None of the children from the control group was taking any medication on the day of testing. One participant from the control group was excluded due to significant eye impairment and two children from the ADHD decided to withdraw from the testing procedure.

Insert Table 1 about here

Measures

Sociodemographic variables. Parents or caregivers reported children age, gender, psychiatric diagnostic and pharmacological treatment, and eye problems.

Several cognitive measures that seem to discriminate between children with ADHD and healthy children were chosen (Frazier et al., 2004).

Executive function measures. The Digit Span and Letter Number Sequencing subtests from the WISC-IV (Wechsler, 2003) were chosen as a measure of working memory where participants have to memorize a series of digits and manipulate them in order to produce correct results. Coding and Symbol Search subtests were used as measures of processing speed. The subject has to visual scan and to discriminate between different items or to produce symbol shapes according to predefined rules. The WISC-IV is adapted on Romanian population (Wechsler, & Dobrean, 2012). d2 Test of attention (Brickenkamp & Zillmer, 1998) was used as a measure of selective attention and concentration performance. The test consists of 558 items distributed over 14 lines with 47 characters per line. The subject has to scan across each line in order to identify and mark the target stimuli while ignoring the non-stimuli. The d2 Test of attention is adapted on Romanian population (Dobrean, 2010).

General intelligence. The Romanian form of Raven Standard Progressive Matrices Plus (Dobrean, Raven, Comşa, Rusu, & Balázsi, 2008; Domuța, Balázsi, Porumb, Rusu, & Comşa, 2003) was used in this study to measure intelligence. The test has 5 sets (A-E) with 12 items per set and a total of 60 items. The items consist of a matrix of figures with an empty position. The subject has to infer what figure should be in the empty position by identifying the relationship between columns and rows.

Further on, we used measures typically used in research focusing on technology use and virtual reality.

The Simulator Sickness Questionnaire (SSQ, Kennedy, Lane, Berbaum, & Lilienthal, 1993) was administrated to children in order to determine any sickness symptoms due to immersion in Virtual Reality. This 16 items measure asks participants to rate on a scale of 0-3 statements that

reflect symptoms after exposure in ClinicaVR: Classroom-CPT (e.g. General discomfort, Blurred vision, Dizziness with eyes open, Nausea). Higher scores represent greater simulator sickness.

An adapted version for children of Cognitive Absorption Scale (CAS, Agarwal & Karahanna, 2000) was used to measure the state of deep involvement with software which predicts usage behavior. It contains four dimensions: temporal dissociation, focused immersion, heightened enjoyment and curiosity. Measures of perceived ease of use, perceived usefulness, and personal innovativeness and behavioral intention to use (Agarwal & Karahanna, 2000) were also used. Our adapted scale consists of 15 items that describe the experience with ClinicaVR: Classroom-CPT or CPT. The number and content of the items were adapted for children aged 7 to 14 years old. Children had to rate on a scale of 1 to 5 their opinion regarding their experience with Virtual Classroom or CPT which were referred to them as computer games (e.g. Time appeared to go by very quickly when I played with the computer). Higher scores indicate higher cognitive absorption, temporal dissociation, focused immersion, heightened enjoyment, curiosity and personal innovativeness, as well as higher perceived ease of use, usefulness and behavioral intention to use.

In order to assess the daily and weekly amount of time spent on the computer, we included one item per each category on which children had to rate on a scale of 1 to 3 their answers (e.g. In general, I like to use the computer). Higher scores reflect greater computer operation knowledge, usage, and enjoyment.

In the current study we used ClinicaVR Classroom, version 2.0.3. It follows a classical AX-type CPT scenario in which the participant is exposed to stimuli over a long period of time and has to respond as quickly as possible to target stimuli and to inhibit any responses to non-

target stimuli. The Virtual Classroom scenario consists of a rectangular classroom populated by desks, a blackboard, windows and doorways on each side of the classroom, pupils and a female teacher in front of the classroom. Children were immersed into the classroom by the use of a head mounted display (HMD) fitted on their head along with headphones. Each participant sat on a desk and had to respond to target items which appeared on the blackboard. The items consisted of letters of the alphabet displayed with fast speed, and the participant was instructed to press the left mouse button only when letter K appears after letter A and to ignore other succession of letters. The Virtual Classroom scenario consisted of 374 stimuli, 55 total targets (AK), with a 1000 milliseconds inter-stimulus interval and 200 milliseconds stimulus duration. In the condition with distractors only auditory distractors were used (school bus noise, someone knocks at the classroom door, footsteps, pencil drops). In the condition without distractors children were immersed in the Virtual Classroom but distractors were disabled.

The AX-type CPT used in this research replicated the stimulus challenges from the ClinicaVR: Classroom-CPT without immersion into the classroom. To be more specific, the number of targets and non-targets, the total number of targets, as well as the inter-stimulus interval and duration were identical with the ClinicaVR: Classroom-CPT scenario. Targets and non-targets were displayed on a computer screen and were identical in color and dimensions with those presented on the Virtual Classroom blackboard. We aimed to create a CPT analogue with ClinicaVR: Classroom-CPT to make the performance measured by the two instruments comparable. The only difference between the two measurement instruments which has been manipulated is the medium of assessment: immersion into the virtual environment and no immersion. Also, in the condition with distractors we used the audio recording from the ClinicaVR: Classroom-CPT and children heard the noises from the classroom through

headphones. In the condition without distractors no distractors were provided. The CPT was designed using Inquisit 3 Software (2012).

The following measures from the ClinicaVR: Classroom-CPT and analogue CPT were used: total correct responses, errors of commission, errors of omission, and the mean reaction time.

Procedure

The study was approved by the Ethics Committee of the Babeș-Bolyai University of Cluj-Napoca, Romania. Permission to conduct the study was obtained from the executive directors of the institutions where the research took place.

Healthy participants were recruited from two elementary public schools in Timisoara, Romania, while children with ADHD were recruited from hospitals and treatment centers in Timisoara and Bucharest. Using the school records, the parents or the legal guardians of the healthy participants were phoned and presented a brief description of the study and if agreed, were mailed the informed consent in order to sign it. Parents or legal guardians accompanying day patients, previously diagnosed by a child psychiatrist based on a clinical interview and using the DSM-IV-TR criteria (American Psychiatric Association, 2000), were given a brief invitation letter explaining the aims of the study and the benefits from taking part (i.e. results from the neuropsychological tests). If agreed, they were asked to signed the written consent. For all the participants, children's assent was taken before the performing the first task.

All participants were screened for a history of psychiatric or neurological disorders, as well for the use of psychotropic medication. The exclusion criteria were the presence of intellectual

disability (an IQ score < 70) (American Psychiatric Association, 2013), autism spectrum disorder and major neurological conditions (e.g. epilepsy).

The same neuropsychological tests were administered in the afternoon to all children, with the difference that half of them received the ClinicaVR: Classroom-CPT assessment while the other half were tested using the CPT. Prior to testing all of the participants received an ID and were randomly assigned to one of the experimental conditions (assessment using ClinicaVR: Classroom-CPT or CPT). Each of the participants was tested with and without distractors with either ClinicaVR: Classroom-CPT or CPT and the order of administration was counterbalanced within-subject. After the informed consent was obtained participants were escorted into the testing room. They first completed the paper-and-pencil neuropsychological measures, in the same order for each participant. Then, they received either the ClinicaVR: Classroom-CPT assessment or the CPT on a Lenovo T400 laptop with a resolution of the display at 1440 × 900 at a refresh rate of 60 Hz. Prior to the beginning of the assessment in the Virtual Classroom, the HMD was adjusted to the child's head. The HMD was an eMagin Z800 3D Visor device. The system was activated and a warm-up session was delivered. The warm-up scenario consisted of the same virtual classroom with identical features. This session allowed the participant to become familiar with the virtual environment, and to adjust if needed, the HMD to provide a safe exposure and to avoid a potential blurry vision. Further on, the warm-up session consisted of a short scenario in which the children were exposed to random numbers that appeared with fast speed on the blackboard and had to response as quickly as possible by clicking the left mouse button whenever the number 9 appeared on the blackboard and to inhibit responses to other numbers. The same scenario was delivered to the participants randomly assigned to the CPT condition with the specification that the scenario was presented on the computer desktop and was

adjusted according to the CPT technical specification presented above. Though in the English version of the Virtual Classroom the instructions are delivered by a teacher, in the current study the instructions were given by the researcher (into Romanian language after being translated from the original version). After having answered to any questions addressed by the children and having ensured that the participants understood the task, the testing began. Depending upon experimental condition half of the children were first tested with distractors and then without distractors, or vice versa. When tested in the condition with distractors they received headphones. Next, all the participants were administered the SSQ, CAS and measures of computer operation knowledge, usage, and enjoyment. All the assessment procedures were delivered in the same order to all the participants. The testing session lasted for approximately two hours. All the primary dependent variables represented by attention performance measured either by the ClinicaVR: Classroom-CPT or by an analogue CPT, such as: total correct responses, errors of commission, errors of omission, and the mean reaction time were recorded automatically by the computer, whereas secondary dependent variables resulted from classical paper-and-pencil assessment were calculated afterwards.

Results

In order to compare ADHD children with controls on executive functions measures, general intelligence, cognitive absorption and computer usage we performed independent samples *t*-test. Table 1 displays the results. Two children reported simulator sickness symptoms as they reported at least once a severe symptom.

Insert Table 2 about here

To examine differences across the four dependent variables we performed a mixed Multivariate Analysis of Covariance (MANCOVA) with (1) the type of group (ADHD and healthy controls), (2) test condition (ClinicaVR: Classroom-CPT or CPT) as between factors, and (3) the test modality condition (with and without distractors) as repeated measures factors controlling for age and IQ which were set as covariates.

First of all, results indicate that age yields a significant effect over the overall attention performance, $V = 0.13$, $F(4, 66) = 2.65$, $p < .05$ while IQ does not, $V = 0.37$, $F(4, 66) = 0.63$, $p > .05$. Results from the mixed MANCOVA using Pillai's trace point out a significant main effect of clinical status on the overall performance on the number of commission, omission errors, total correct hits and reaction time, $V = 0.30$, $F(4, 66) = 7.06$, $p < .001$. Next, Sidak corrected post hoc tests showed that on ClinicaVR: Classroom-CPT ADHD children perform worse than controls on commission errors ($p < .05$, $d = 1.03$), omission errors ($p < .01$, $d = 1.09$), total correct responses ($p < .01$, $d = 1.15$), and slower on reaction time ($p < .01$, $d = 0.59$). In case of CPT children with ADHD perform worse than controls on commissions ($p < .01$, $d = 1.3$) and omissions ($p < .05$, $d = 1.09$), and better on total correct responses ($p < .01$, $d = 1.21$). However, no significant differences between the two groups were on reaction time ($p > .05$). There was also a significant main effect of test condition on the dependent variables, $V = 0.53$, $F(4, 66) = 19.14$, $p < .001$. However, Sidak corrected post hoc tests revealed that for children with ADHD differences on commission errors, omission errors and total correct responses between assessment using Virtual Classroom and CPT are not significant ($p > .05$), but reaction time to targets was slower in the ClinicaVR: Classroom-CPT type assessment ($p < .01$, $d = 2.05$). For healthy controls, Sidak corrected post hoc tests pointed out significant differences only on

reaction time to targets between virtual reality-based assessment and CPT ($p < .01$, $d = 2.04$), with slower response time rates in virtual reality. For the number of commissions ($p > .05$), omission errors ($p > .05$), and total correct responses ($p > .05$) no significant differences have emerged. Next, results revealed a significant main effect of test modality on the overall performance on number of commission, omission errors, total correct hits and reaction time, $V = 0.17$, $F(4, 66) = 3.44$, $p < .05$. Such a result reflects the fact that the presence or absence of distractors yields an influence over the performance obtained by both children with ADHD and healthy controls. However, Sidak post hoc tests revealed that the only significant differences between the condition with and without distractors emerged on omissions and total correct responses in Virtual Classroom ($p < .05$) in case of children with ADHD that seem to commit more omissions ($d = 0.56$) and display less correct responses in the condition with distractors ($d = 0.42$). Next, for the CPT condition Sidak post hoc tests show significant differences between the conditions with or without distractors only in case of total correct responses where children with ADHD show less correct responses in the condition with distractors ($d = 0.38$) (see Table 2). In case of healthy controls no significant differences emerge on none of the conditions ($p > .05$).

Further on, the interaction effect between clinical status and test condition on the outcome variables is not significant, $V = 0.08$, $F(4, 66) = 1.60$, $p > .05$, that indicates that the differences on overall attention performance obtained by both ADHD children and healthy controls is not influenced by the assessment using ClinicaVR: Classroom-CPT or CPT. Similarly, there was a non-significant interaction between the assessment with or without distractors and the clinical status of the participants, $V = 0.09$, $F(4, 66) = 1.76$, $p > .05$. Thus, despite the test modality both children with ADHD and healthy controls perform similarly on the

outcome measures when measured with Virtual Classroom or CPT with or without distractors. Also, performance is not influenced by type of test condition with or without distractors, $V = 0.09$, $F(4, 66) = 1.64$, $p > .05$. Further on, when testing the interaction effect between clinical status, test condition and test modality results show a non-significant effect on overall attention performance, $V = 0.10$, $F(4, 66) = 1.91$, $p > .05$

In order to examine our fourth objective, we performed independent samples *t*-test. Results point out no significant differences between the ClinicaVR: Classroom-CPT and the CPT on none of the cognitive absorption dimensions: temporal dissociation ($p > .05$), focused immersion ($p > .05$), heightened enjoyment ($p > .05$), curiosity ($p > .05$), personal innovativeness ($p > .05$), as well as perceived ease of use ($p > .05$), usefulness ($p > .05$), and behavioral intention to use ($p > .05$).

Supplementary analysis

In order to investigate potential differences between treated and non-treated children with ADHD we performed a Kruskal-Wallis test for each of the outcomes: commissions, omissions, total correct responses and total reaction time assessed with the ClinicaVR: Classroom-CPT or CPT. A total of eight Kruskal-Wallis tests resulted. The between-subject factor was type of pharmacological treatment taken in the day of testing: stimulant medication (i.e. methylphenidate), non-stimulant medication (i.e. atomoxetine), other drugs (i.e. typical and atypical neuroleptics, mood stabilizers 34.78 %) and no medication. Because we had small sample of participants in each condition we decided that a more appropriate statistical test would be a non-parametric test that ranks the data, although a non-parametric test has a lower statistical power (Field, 2009). Results show that no significant differences between treatment conditions

emerge on the number of commissions, $H(3) = 4.10$, $p > .05$, omissions, $H(3) = 0.03$, $p > .05$, total correct responses, $H(3) = 0.03$, $p > .05$, and reaction time, $H(3) = 3.07$, $p > .05$ in Virtual Classroom with distractors. No significant differences emerge in Virtual Classroom without distractors on neither commissions, $H(3) = 5.68$, $p > .05$, omissions, $H(3) = 1.05$, $p > .05$, total correct responses, $H(3) = 1.97$, $p > .05$, and reaction time, $H(3) = 2.47$, $p > .05$. Similarly, no significant differences in performance are reported for the CPT with distractors on neither parameters: commissions, $H(3) = 2.62$, $p > .05$, omissions, $H(3) = 2.07$, $p > .05$, total correct responses, $H(3) = 3.11$, $p > .05$, and reaction time, $H(3) = 4.33$, $p > .05$. For the CPT without distractors' outcomes results also show no significant differences between medication conditions on commissions, $H(3) = 3.17$, $p > .05$, omissions, $H(3) = 0.71$, $p > .05$, total correct responses, $H(3) = 0.71$, $p > .05$, and reaction time, $H(3) = 1.88$, $p > .05$.

Discussion

The current study aimed to investigate the discriminant validity of a virtual reality-based measure for attention assessment in ADHD children and to examine the task difficulty of ClinicaVR: Classroom-CPT compared to a well-established measure of attention delivered via computer known as CPT. Both measures, the ClinicaVR: Classroom-CPT and CPT contained a scenario with and without distractors to assess the effect of distractors over performance.

Our results pointed out that ClinicaVR: Classroom-CPT discriminated between participants with ADHD and healthy controls because ADHD children performed, as expected worse on correct responses, had more commissions and omissions errors, and slower reaction time to targets than controls. The fact that, ADHD participants made more omission and commission errors and gave more incorrect responses, is in line with the results provided by

other studies conducted on this topic that used the same version of ClinicaVR: Classroom-CPT, but with different stimulus duration, inter-stimulus interval and format (Bioulac et al., 2012; Parsons et al., 2007; Pollak et al, 2009). In case of reaction time to targets, in our study we obtained significant differences between ADHD participants and healthy ones with slower response rates for ADHD. Another study which obtained similar results was conducted by Pollak et al. (2009). However, a study which has focused on the same outcomes did find significant differences between the two types of participants, but the trend in results showed faster response rates for ADHD participants than controls on reaction time to correct hits (Bioulac et al., 2012). Both studies used a non-treated sample of ADHD children, while ours had a treated sample with no treatment effect over performance. Contradictory results emerge if we consider the study conducted by Adams et al. (2009) that had a treated sample of ADHD children (methylphenidate and atomoxetine) reports only a tendency towards significance on the Virtual Classroom parameters between ADHD children and healthy controls. Based on such results we can argue that medication effect over attention performance measured in a virtual environment are not still well documented, but might suggest a minor improvement on attention performance. If we examine our study's mean effect sizes between ADHD and healthy controls (see Table 2) and the effect sizes from the studies cited above (see Negut et al., 2016b for effect sizes) we speculate that medication (methylphenidate and atomoxetine) has a minimum influence over attention performance. However, there is need for further investigation with larger samples for increased power to detect any treatment effect if any.

Concerning the CPT, we found similar results except for the reaction time to targets, where no significant differences between the two groups emerged. This suggests that, in case of reaction time, the CPT does not discriminate between ADHD children and healthy controls.

Also, a meta-analysis that focused on comparing performance between participants with ADHD and healthy participants showed medium to large effect sizes for omission and commission errors and medium effect sizes for reaction time to targets (Huang-Pollock, Karalunas, Tam, & Moore, 2012; Losier et al., 1996). In the present study, when comparing between performance in ClinicaVR: Classroom-CPT between ADHD participants and healthy controls on outcome variables, we obtained medium to large effect sizes. For commission errors (d = 1.03, overlap percent = 61.71%), omission errors (d = 1.09, overlap percent = 58.23%), total correct responses (d = 1.15, overlap percent = 54.85%) results show large effect sizes while for reaction time results point out a medium effect size (d = 0.59, overlap percent = 76.42%). A similar pattern was found for the comparison between the two groups on the CPT-based assessment with large effect sizes for commissions (d = 1.3, overlap percent = 51.57%) and omissions (d = 1.09, overlap percent = 58.23%), total correct responses (d = 1.21, overlap percent = 54.85%), and a medium effect for reaction time to targets (d = 0.73, overlap percent = 68.92%). As it can be seen, there is a similar overlap percent between the two types of measures which suggests that both measures have similar classification accuracy. Based on these results, the most efficient diagnostic marker for ADHD is the number of total correct responses on both Virtual Classroom and CPT, while the least efficient diagnostic marker is the reaction time to targets.

Regarding our second objective, data analysis showed that for ADHD children there are no significant differences between the assessment using ClinicaVR: Classroom-CPT and the CPT on commissions, omission errors and total correct responses. Significant differences were found for reaction time to targets with longer reaction time in virtual reality and a large effect size (d = 2.05, overlap percent = 29.37%). In case of normal participants, significant differences between Virtual Classroom and CPT were obtained on reaction time, with slower reaction time

in virtual reality compared to the computerized assessment and a large effect size (d = 2.04, overlap percent = 31.73%). Results pointed out non-significant differences between the performance on commission and omission errors and on total correct responses measured with the two measurement instruments. Two studies that focused on identifying differences among ADHD children on Virtual Classroom and an analogue CPT (Pollak et al., 2009; 2010) showed that participants tend to make more omission errors in virtual reality and have slower reaction time. In the current study, we identified significant differences between the two measures only for reaction time, for both ADHD children and healthy controls. We identified slower reaction time in virtual reality for ADHD children. Healthy children perform similar in the Virtual Classroom with longer response time compared to the CPT. It seems that between the results of our study and Pollak et al. (2009; 2010), the only difference is accounted for the number of omissions. Several explanations might be taken into account. Both types of CPTs were an AX-type CPT, but the two versions were different on the total number of stimuli, on the stimulus and inter-stimulus interval. Also, Pollak et al. (2009; 2010) used mixed distractors, while we used only auditory distractors that might have impacted the results. Next, our study had a sample of children with the mean age of 9 years and Pollak et al. (2009; 2010) had a sample of adolescents with a mean age ranging from 12 to 13 years old. The influence of age over ADHD symptoms is documented in the literature, with a general decrease of ADHD symptoms over time (Biederman, Mick, & Faraone, 2000). Further on, Pollak et al. (2009) used a non-treated sample, while Pollak et al. (2010) methylphenidate versus placebo. In the current study, although parts of the sample were taking different types of medication, this did not impact the attention performance on none of the outcomes. Possible explanations are the small size of the groups compared and the time the experiment took place with regards to the effects of the used medication were less important.

Specifically, the stimulant effect of the extended-release formulation of methylphenidate, as well as the sedative effects of the neuroleptic or mood stabilizing medication are usually less strong in the afternoon (while atomoxetine should have had little impact, if any).

Overall, we consider that the current study offers limited support for the assumption that a CPT embedded in virtual reality like ClinicaVR: Classroom-CPT has an increased task difficulty because reaction time tend to be slower in difficult task conditions (Andreassi, 2007; Gevins, Smith, McEvoy, & Yu, 1997). However, large effect sizes for the comparison between Virtual Classroom with CPT on reaction time for both ADHD participants and healthy controls strengthen the task difficulty hypothesis of the ClinicaVR: Classroom-CPT. In turn, we can assume that to some extent virtual reality offers a more ecological assessment which better captures the real level of development of attention processes.

In case of our third objective, that aimed to investigate the effect of distractors on the performance of ADHD participants and healthy controls on ClinicaVR: Classroom-CPT and the CPT, results showed a significant main effect of test modality on the overall performance on the CPT parameters. Overall, this is in line with previous data that suggests that adding distractors into the virtual environment increases the ecological validity and task complexity (Areces et al., 2016; Erez et al., 2013; Ku et al., 2003; Rand, 2009; Rand et al., 2007). Previous studies that used virtual classroom scenarios for attention assessment of children with ADHD show the negative effect of adding distractors yields over performance (Adams et al., 2009; Bioulac et al., 2012; Diaz-Orueta et al., 2014; Iriarte et al., 2012; Rizzo et al., 2000). Also, adding distractors into a CPT seems to improve the utility of the CPT in ADHD diagnosis while reducing performance and increasing task difficulty (Berger & Cassuto, 2014; Uno et al., 2006).

In the present research, results point out differences in performance in the assessment condition with distractors and without distractors. Post hoc comparisons showed that, for commissions and reaction time, there are no differences across the assessment using ClinicaVR: Classroom-CPT and CPT with or without distractors for ADHD children or healthy controls. However, for omission errors and total correct responses, results pointed out better correct responses and much more omission errors for ADHD children when assessed in ClinicaVR: Classroom-CPT with distractors than without distractors (d = 0.56). Next, when we took into account the differences between the assessment using CPT with or without distractors in case of ADHD children, post hoc comparisons showed that ADHD children made less correct responses in the condition with distractors (d = 0.42). It appears that the incremental value of adding auditory distractors in distinguishing ADHD children from controls on virtual reality measures or an analogue CPT does find support from the current results. However, this assumption is limited to omissions and total correct responses. Omission errors result from inattention (Berwid et al., 2005; Brocki & Bohlin, 2006; Rizzo et al., 2000). Adding distractors into the virtual environment can distract the child and makes him more prone to miss the correct targets. Subsequently, the number of omission errors increases. Similarly, for total correct responses the fact that an environment embeds distractors can make the child less attentive to targets and miss the correct ones. In plus, it is important to note that we only included auditory distractors while excluding visual distractors. Therefore, we might expect an even large effect of distractors on performance with mixed audio-visual distractors.

Further on, when we examine the effect of auditory distractors over the traditional AX-type CPT data shows no significant differences between the condition with or without distractors except for the total number of correct responses in case of ADHD participants. For healthy

controls no such differences emerge. On a general level, the results from the present study are similar with other research reports that show that ADHD children are more influenced by distractors than controls. In case of ADHD children when we take into account the amount of CPT outcomes that are negatively influenced by the distractors studies show that the number of errors are most affected by auditory or visual distractors (Berger & Cassuto, 2014; Uno et al., 2006). In our study, omission errors were not affected by auditory distractors, but the total correct responses were negatively influenced by them. We used highly ecological auditory distractors that seem to affect sustained attention, but their negative effect is rather small (d = 0.38).

Based on the current results, we consider that highly ecological distractors negatively impact sustained attention and increase inattention symptoms in case of ADHD participants. This negative effect is more powerful in a ClinicaVR: Classroom-CPT scenario compared to an analogue CPT. Also our results can be explained in terms of delay aversion, a motivational process. According to this model, children with ADHD have an impulsive preference for immediate rewards and often get distracted during delay intervals (Sonuga-Barke, 2003; Sonuga-Barke, Taylor, Sembi, & Smith, 1992). Adding distractors might impact the perceived length of the task during the ClinicaVR: Classroom-CPT or CPT testing. More precisely, environments rich in stimuli like the ClinicaVR: Classroom-CPT with distractors make time pass more quickly for children with ADHD while negatively impacting vigilance or sustained attention. This results, as our study suggests, in an increased number of omission errors and reduced number of correct responses. Similarly, our study points out a decrease in sustained attention performance that is reflected in the reduced number of correct responses in case of a CPT with distractors

compared to the same CPT without distractors. Again, distractors help time fly and enhance the distractibility during delay intervals.

The auditory distractors from the ClinicaVR classroom plus the virtual scenario in which the child is immersed increase the task difficulty because they recreate a real classroom with real "attention challenges" compared to the more "sterile" CPT. Nevertheless, the magnitude of the effect size between the conditions with and without distractors pointed out that the benefits of adding auditory distractors into the Virtual Classrooms scenario or into the analogue AX-type CPT are limited.

For the fourth objective, that aimed to compare the ClinicaVR: Classroom-CPT with an analogue CPT on different cognitive absorption dimensions: temporal dissociation, focused immersion, heightened enjoyment, curiosity, personal innovativeness, perceived ease of use, usefulness, and behavioral intention to use, the results displayed no significant differences between the two assessment tools on neither dimension. Although we expected more favorable ratings in favor of ClinicaVR: Classroom-CPT based on the findings of Pollak et al. (2009; 2010) our results did not support our initial hypothesis. As a consequence, we can say that children perceived both measures similarly on cognitive absorption. A possible explanation is based on the fact that children appreciate technology and previous exposure to technology yields an impact over its acceptance (Holzinger, Searle, & Wernbacher, 2011). Children may be attracted by the computer technology in general and for them the overall testing experience via computer with or without immersion with a HMD was perceived as enjoyable.

Limitations and conclusions

The present research has several limitations. First, we have included in our sample children with comorbidity. However, because it is considered that comorbidity in ADHD is rather high (Jensen, Martin, & Cantwell, 1997), we can consider this potential threat to internal validity as an evidence for the external validity of our study.

Although results from the current research provide evidence for the diagnostic validity of the ClincaVR Classroom and several studies have focused on providing evidence for construct and convergent validity (Adams et al., 2009; Bioulac et al., 2012; Nolin et al., 2016; Parsons et al., 2007; Pollak et al., 2009), future studies might consider providing norms and performing reliability analysis. For instance, another virtual classroom CPT type scenario, AULA Nesplora is well validated on a Spanish sample (Iriate et al., 2012). Other studies can investigate the predictive validity of the ClincaVR Classroom in relationship to real-life performance or other objective criteria. Future studies might consider upgrading the current graphics of Virtual Classroom. The graphics of video games are developing with fast speed and children are usually connected to the new technological games releases. An upgraded version of the ClincaVR Classroom's graphics might increase immersion and enhance the similarity with the real world environment.

Overall, results from the current research brings evidence in favor of the diagnostic validity of Virtual Classroom because the measure has diagnostic utility as it discriminates between ADHD children and healthy controls on all CPT's parameters: total correct responses, the number of commission and omission errors and on reaction time to targets. Our results offers limited support to the assumption that ClinicaVR: Classroom-CPT is a more ecological assessment instrument which has an increased task difficulty compared to the CPT because ADHD participants showed slower reaction time rates in virtual reality, while healthy controls

also had a slower reaction time in virtual reality. Nevertheless, it seems that adding auditory distractors to the virtual environment does negatively impact the attention performance obtained by ADHD children, but not that of healthy participants.

References

Adams, R., Finn, P., Moes, E., Flannery, K., & Rizzo, A. A. (2009). Distractibility in Attention/Deficit/ Hyperactivity Disorder (ADHD): the Virtual Reality Classroom. *Child Neuropsychology, 15*(2), 120-135. doi: 10.1080/09297040802169077

Agarwal, R., & Karahanna, E. (2000). Time flies when you're having fun: Cognitive absorption and beliefs about information technology usage. *MIS quarterly, 24*(4), 665-694. doi: 10.2307/3250951

American Psychiatric Association. (2000). *Diagnostic and statistical manual of mental disorders* (4th ed.). Washington, DC: American Psychiatric Association.

American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders* (5th ed.). Washington, DC: American Psychiatric Association.

Andreassi, J. L. (2007). *Psychophysiology: Human behavior & physiological response*. NJ: Lawrence Erlbaum.

Areces, D., Rodríguez, C., García, T., Cueli, M., & González-Castro, P. (2016). Efficacy of a Continuous Performance Test Based on Virtual Reality in the Diagnosis of ADHD and Its Clinical Presentations. *Journal of Attention Disorders*, 1-11. doi: 10.1177/1087054716629711

Barkley, R. A. (1991). The ecological validity of laboratory and analogue assessment methods of ADHD symptoms. *Journal of abnormal child psychology, 19*(2), 149-178. doi: 10.1007/BF00909976

Barkley, R. A. (2006). *Attention deficit hyperactivity disorder: A handbook for diagnosis and treatment.* New York, NY: Guilford.

Barkley, R. A., Grodzinsky, G., & DuPaul, G. J. (1992). Frontal lobe functions in attention deficit disorder with and without hyperactivity: A review and research report. *Journal of abnormal child psychology, 20*(2), 163-188. doi: 10.1007/BF00916547

Berger, I., & Cassuto, H. (2014). The effect of environmental distractors incorporation into a CPT on sustained attention and ADHD diagnosis among adolescents. *J Neurosci Methods, 222*, 62-68. doi: 10.1016/j.jneumeth.2013.10.012

Berwid, O. G., Curko Kera, E. A., Marks, D. J., Santra, A., Bender, H. A., & Halperin, J. M. (2005). Sustained attention and response inhibition in young children at risk for Attention Deficit/Hyperactivity Disorder. *Journal of Child Psychology and Psychiatry, 46*(11), 1219-1229. doi: 10.1111/j.1469-7610.2005.00417.x

Biederman, J., Mick, E., & Faraone, S. V. (2000). Age-dependent decline of symptoms of attention deficit hyperactivity disorder: impact of remission definition and symptom type. *American Journal of Psychiatry, 157*(5), 816–818.

Bioulac, S., Lallemand, S., Rizzo, A., Philip, P., Fabrigoule, C., & Bouvard, M. P. (2012). Impact of time on task on ADHD patient's performances in a virtual classroom. *European Journal of Paediatric Neurology, 16*, 514-521. doi: 10.1016/j.ejpn.2012.01.006

Brickenkamp, R., & Zillmer, E. A. (1998). *d2 Test of Attention.* Göttingen, Germany: Hogrefe & Huber.

Bohil, C. J., Alicea, B., & Biocca, F. A. (2011). Virtual reality in neuroscience research and therapy. *Nature Reviews Neuroscience, 12*(12), 752-762. doi: 10.1038/nrn3122

Brocki, K. C., & Bohlin, G. (2006). Developmental change in the relation between executive functions and symptoms of ADHD and co-occurring behaviour problems. *Infant and Child Development, 15*(1), 19-40. doi: 10.1002/icd.413

Chaytor, N., & Schmitter-Edgecombe, M. (2003). The Ecological Validity of Neuropsychological Tests:

A Review of the Literature on Everyday Cognitive Skills. *Neuropsychology Review, 13*(4), 181-197. doi: 10.1023/B:NERV.0000009483.91468.fb

Chaytor, N., Schmitter-Edgecombe, M., & Burr, R. (2006). Improving the ecological validity of executive functioning assessment. *Archives of Clinical Neuropsychology, 21*(3), 217-227. doi: 10.1016/j.acn.2005.12.002

Conners, C. K. (1995). *Conners' Continuous Performance Test.* Toronto: Multi-Health Systems.

Conners, C. K., Epstein, J. N., Angold, A., & & Klaric, J. (2003). Continuous performance test performance in a normative epidemiological sample. *Journal of abnormal child psychology, 31*(5), 555-562. doi: 10.1023/A:1025457300409

Díaz-Orueta, U., Garcia-López, C., Crespo-Eguílaz, N., Sánchez-Carpintero, R., Climent, G., & Narbona, J. (2014). AULA virtual reality test as an attention measure: Convergent validity with Conners' Continuous Performance Test. *Child Neuropsychology, 20*(3), 328-342. doi: 10.1080/09297049.2013.792332

Dobrean, A. (2010). *Test d2 – Test de atenție* [d2 Test of Attention]. Cluj-Napoca, Romania: Romanian Testing Services.

Dobrean, A., Raven, J., Comșa, M., Rusu, C., & Balázsi, R. (2008). The Romanian standardisation

of the Standard Progressive Matrices Plus: Sample and general results. In J. Raven & C. J. Raven (Eds.), *Uses and abuses of intelligence: Studies advancing Spearman and Raven's quest for non arbitrary metrics*. Cluj-Napoca, Romania: Romanian Testing Services.

Domuţa, A., Balázsi, R., Porumb, M., Rusu, C., & Comşa, M. (2003). *Standardizarea pe populaţia României a testului Matrici Progresive Raven Standard Plus în Matricile Progresive Raven Standard. Manual de utilizare* [The Romanian standardisation of the Standard Progressive Matrices Plus. Technical Manual]. ClujNapoca, Romania: Romanian Testing Services.

Epstein, J. N., Erkanli, A., Conners, C. K., Klaric, J., Costello, J. E., & Angold, A. (2003). Relations between continuous performance test performance measures and ADHD behaviors. *Journal of abnormal child psychology, 31*(5), Epstein, J. N., Erkanli, A., Conners, C. K., Klaric, J., Costello, J. E., & Angold, A. (2003). Relations between continuous performance test performance measures and ADHD behaviors. Journal of abnormal child psychology, 2031(2005), 2543-2554. doi: 10.1023/A:1025405216339

Erez, N., Weiss, P. L., Kizony, R., & Rand, D. (2013). Comparing Performance Within a Virtual Supermarket of Children With Traumatic Brain Injury to Typically Developing Children: A Pilot Study. *OTJR: Occupation, Participation & Health, 33*(44), 218-227. doi: 10.3928/15394492-20130912-04

Field, A. (2009). *Discovering statistics using IBM SPSS statistics* (3rd ed.). London, UK: Sage.

Frazier, T. W., Demaree, H. A., & Youngstrom, E. A. (2004). Meta-analysis of intellectual and neuropsychological test performance in attention-deficit/hyperactivity disorder. *Neuropsychology, 18*(3), 543-555. doi: 10.1037/0894-4105.18.3.543

Gamberini, L. (2000). Virtual Reality as a New Research Tool for the Study of

Human Memory. *Cyberpsychol Behav, 3*(3), 337-342. doi: 10.1089/10949310050078779

Gevins, A., Smith, M. E., McEvoy, L., & Yu, D. (1997). High-resolution EEG Mapping of Cortical Activation Related to Working Memory: Effects of Task Difficulty, Type of Processing, and Practice. *Cerebral Cortex, 7*(4), 374–385. doi: 10.1093/cercor/7.4.374

Grodzinsky, G. M., & Barkley, R. A. (1999). Predictive power of frontal lobe tests in the diagnosis of attention deficit hyperactivity disorder. *The Clinical Neuropsychologist, 13*(1), 12-21. doi: 10.1076/clin.13.1.12.1983

Gualtieri, T., & Johnson, L. G. (2005). ADHD: Is objective diagnosis possible? *Psychiatry, 2*(11), 44–53.

Holzinger, A., Searle, G., & Wernbacher, M. (2011). The effect of previous exposure to technology on acceptance and its importance in usability and accessibility engineering. *Universal Access in the Information Society, 10*(3), 245-260. doi: 10.1007/s10209-010-0212-x

Huang-Pollock, C. L., Karalunas, S. L., Tam, H., & Moore, A. N. (2012). Evaluating vigilance deficits in ADHD: a meta-analysis of CPT performance. *Journal of abnormal psychology, 121*(2), 360-371. doi: 10.1037/a0027205

Inquisit (Version 3) [Computer software]. Seattle, WA: Millisecond Software.

Iriarte, Y., Diaz-Orueta, U., Cueto, E., Irazustabarrena, P., Banterla, F., & Climent, G. (2012). AULA—Advanced virtual reality tool for the assessment of attention: normative study in Spain. *Journal of Attention Disorders, XX*(X), 1-27. doi: 10.1177/1087054712465335

Jensen, P. S., Martin, D., & Cantwell, D. P. (1997). Comorbidity in ADHD: implications for research, practice, and DSM-V. *Journal of the American Academy of Child & Adolescent Psychiatry, 36*(8), 1065-1079. doi: 10.1097/00004583-199708000-00014

Kennedy, R. S., Lane, N. E., Berbaum, K. S., & Lilienthal, M. G. (1993). Simulator sickness questionnaire: An enhanced method for quantifying simulator sickness. *The International Journal of Aviation Psychology, 3*(3), 203-220. doi: 10.1207/s15327108ijap0303_3

Ku, J., Cho, W., Kim, J. J., Peled, A., Wiederhold, B. K., Wiederhold, M. D., & Kim, S. I. (2003). A virtual environment for investigating schizophrenic patients' characteristics: assessment of cognitive and navigation ability. . *CyberPsychology & Behavior, 6*(4), 397-404. doi: 10.1089/109493103322278781

Lange, K. W., Hauser, J., Lange, K. M., Makulska-Gertruda, E., Takano, T., Takeuchi, Y., . . . Tucha, O. (2014). Utility of cognitive neuropsychological assessment in attention-deficit/hyperactivity disorder. *ADHD Attention Deficit and Hyperactivity Disorders, 6*(4), 241-248. doi: 10.1007/s12402-014-0132-3

Leark, R. A., Greenberg, L. M., Kindschi, C. L., Dupuy, T. R., & Hughes, S. J. (2007). *Test of variables of attention Continuous Performance Test: Professional manual*. Los Alamitos, CA: TOVA.

Losier, B. J., McGrath, P. J., & Klein, R. M. (1996). Error Patterns on the Continuous Performance Test in Non-Medicated and Medicated Samples of Children With and Without ADHD: A Meta-Analytic Review. *Journal of Child Psychology and Psychiatry, 37*(8), 971-987. doi: 10.1111/j.1469-7610.1996.tb01494.x

Matheis, R. J., Schultheis, M. T., Tiersky, L. A., DeLuca, S. R., Millis, S. R., & S., R. A. (2007). Is Learning and Memory Different in a Virtual Environment? . *The Clinical Neuropsychologist, 21*(1), 146-161. doi: 10.1080/13854040601100668

Neguţ, A., Matu, S. A., Sava, F. A., & David, D. (2016a). Task difficulty of virtual reality-based assessment tools compared to classical paper-and-pencil or computerized measures: A

meta-analytic approach. *Computers in Human Behavior, 54*, 414-424. doi: 10.1016/j.chb.2015.08.029

Neguț, A., Matu, S. A., Sava, F. A., & David, D. (2016b). Virtual reality measures in neuropsychological assessment: a meta-analytic review. *The Clinical Neuropsychologist, 30*(2), 165-184. doi: 10.1080/13854046.2016.1144793

Nigg, J. T., Hinshaw, S. P., & Halperin, J. M. (1996). Continuous performance test in boys with attention deficit hyperactivity disorder: Methylphenidate does response and relations with observed behaviors. *Journal of Clinical Child Psychology, 25*(3), 330-340. doi: 10.1207/s15374424jccp2503_9

Nolin, P., Stipanicic, A., Henry, M., Lachapelle, Y., Lussier-Desrochers, D., & Allain, P. (2016). ClinicaVR: Classroom-CPT: A virtual reality tool for assessing attention and inhibition in children and adolescents. *Computers in Human Behavior, 59*, 327-333. doi: 10.1016/j.chb.2016.02.023

Parsey, C. M., & Schmitter-Edgecombe, M. (2013). Applications of technology in neuropsychological assessment. *The Clinical Neuropsychologist, 27*(8), 1328-1361. doi: 10.1080/13854046.2013.834971

Parsons, T. D., Bowerly, T., Buckwalter, J. G., & Rizzo, A. A. (2007). A controlled clinical comparison of attention performance in children with ADHD in a virtual reality classroom compared to standard neuropsychological methods. *Child Neuropsychology, 13*(4), 363-381. doi: 10.1080/13825580600943473

Parsons, T. D., & Courtney, C. G. (2014). An initial validation of the Virtual Reality Paced Auditory Serial Addition Test in a college sample. *J Neurosci Methods, 222*, 15-23. doi: 10.1016/j.jneumeth.2013.10.006

Pollak, Y., Weiss, P. L., Rizzo, A. A., Weizer, M., Shriki, L., Shalev, R. S., & Gross-Tsur, V. (2009). The utility of a continuous performance test embedded in virtual reality in measuring ADHD-related deficits. *Journal of Developmental & Behavioral Pediatrics, 30*(1), 2-6. doi: 10.1097/DBP.0b013e3181969b22

Preston, A. S., Fennell, E. B., & Bussing, R. (2005). Utility of a CPT in diagnosing ADHD among a representative sample of high-risk children: a cautionary study. *Child Neuropsychology, 11*(5), 459-469. doi: 10.1080/09297040591001067

Rand, D., Basha-Abu Rukan , S., Weiss, P. L., & Katz, N. (2009). Validation of the Virtual MET as an assessment tool for executive functions. *Neuropsychological Rehabilitation: An International Journal of Head Trauma Rehabilitation, 19*(4), 583-602. doi: 10.1080/09602010802469074

Rand, D., Katz, N., Shahar, M., Kizony, R., & Weiss, P. L. (2005). The Virtual Mall: A Functional Virtual Environment for Stroke Rehabilitation. In B. C. Wiederhold , G. Riva & A. H. Bullinger (Eds.), *Annual Review of Cybertherapy and Telemedicine:*

A Decade of VR (Vol. 3, pp. 193-198). San Diego, CA: Interactive Media Institute.

Rand, D., Katz, N., & Weiss, P. L. (2007). Evaluation of virtual shopping in the VMall: comparison of post-stroke participants to healthy control groups. *Disabil Rehabil, 29*(22), 1710-1719. doi: 10.1080/09638280601107450

Riccio, C. A., & Reynolds, C. R. (2001). Continuous performance tests are sensitive to ADHD in adults but lack specificity. *Annals of the New York Academy of Sciences, 931*(1), 113-139. doi: 10.1111/j.1749-6632.2001.tb05776.x

Rizzo, A. A., Bowerly, T., Buckwalter, J. G., Klimchuk, D., Mitura, R., & Parsons, T. D. (2006). A Virtual Reality Scenario for All Seasons: the Virtual Classroom. *CNS Spectrums, 11*(1), 35-44. doi: 10.1017/S1092852900024196

Rizzo, A. A., Buckwalter, J. G., Bowerly, T., Van Der Zaag, C., Humphrey, L., Neumann, U., & Sisemore, D. (2000). The Virtual Classroom: A Virtual Reality Environment for the Assessment and Rehabilitation of Attention Deficits. *CyberPsychology & Behavior, 3*(3), 483-499. doi: 10.1089/10949310050078940

Robertson, I. H., Ward, T., Ridgeway, V., & Nimmo-Smith, I. (1996). The structure of normal human attention: The Test of Everyday Attention. *Journal of the International Neuropsychological Society, 2*(06), 525-534. doi: 10.1017/S1355617700001697

Rosvold, H. E., Mirsky, A. F., Sarason, I., Bransome, E. D., & Beck, L. H. (1956). A continuous performance test of brain damage. *Journal of Consulting Psychology, 20*(5), 343-350. doi: 10.1037/h0043220

Sandford, J. A., & Turner, A. (1995). *Manual for the Integrated Visual and Auditory Continuous Performance Test*. Richmond, VA: Braintrain.

Schultheis, M. T., Himelstein, J., & Rizzo, A. A. (2002). Virtual Reality and Neuropsychology: Upgrading the Current Tools. *Journal of Head Trauma Rehabilitation, 17*(5), 378-394.

Servera, J., & Llabrés, J. (2004). *Children Sustained Attention Task (CSAT)*. Madrid, Spain: TEA.

Servera, M., & Cardo, E. (2006). Children sustained attention task (CSAT): Normative, reliability, and validity data. *International Journal of Clinical and Health Psychology, 6*(3), 697-707.

Siemerkus, J., Irle, E., Schmidt-Samoa, C., Dechent, P., & Weniger, G. (2012). Egocentric spatial learning in schizophrenia investigated with functional magnetic resonance imaging. *Neuroimage Clin, 1*(1), 153-163. doi: 10.1016/j.nicl.2012.10.004

Sonuga-Barke, E. J. (2003). The dual pathway model of AD/HD: an elaboration of neuro-developmental characteristics. *Neuroscience & Biobehavioral Reviews, 22*(7), 593-604. doi: 10.1016/j.neubiorev.2003.08.005

Sonuga-Barke, E. J. S., Taylor, E., Sembi, S., & Smith, J. (1992). Hyperactivity and delay aversion—I. The effect of delay on choice. *Journal of Child Psychology and Psychiatry, 33*(2), 387-398. doi: 10.1111/j.1469-7610.1992.tb00874.x

Spooner, D. M., & Pachana, N. A. (2006). Ecological validity in neuropsychological assessment: a case for greater consideration in research with neurologically intact populations. *Archives of Clinical Neuropsychology, 21*(4), 327-337. doi: 10.1016/j.acn.2006.04.004

Uno, M., Abe, J., Sawai, C., Sakaue, Y., Nishitani, A., Yasuda, Y., . . . Takeuchi, Y. (2006). Effect of additional auditory and visual stimuli on continuous performance test (noise-generated CPT) in AD/HD children–usefulness of noise-generated CPT. *Brain & Development, 28*(3), 162–169. doi: 10.1016/j.braindev.2005.06.007

Van der Elst, W., Van Boxtel, M. P., Van Breukelen, G. J., & Jolles, J. (2008). A large-scale cross-sectional and longitudinal study into the ecological validity of neuropsychological test measures in neurologically intact people. *Archives of Clinical Neuropsychology, 23*(7), 787-800. doi: 10.1016/j.acn.2008.09.002

Wasserman, J. D., & Bracken, B. A. (2003). Psychometric characteristics of assessment procedures. In J. R. Graham & J. A. Naglieri (Eds.), *Handbook of Psychology* (pp. 43-66). New Jersey: John Wiley & Sons.

Wechsler, D. (2003). *Wechsler Intelligence Scale for Children-WISC-IV*. San Antonio, TX: Psychological Corporation.

Wechsler, D., & Dobrean, A. (2012). *Scala de Inteligenţă pentru copii Wechsler – ediţia a IVa (WISCIV). Manual tehnic şi de interpretare* [Wechsler Intelligence Scale for Children-WISC-IV (WISC-IV). Technical and interpretive manual (3rd ed.)]. Cluj-Napoca, Romania: Romanian Testing Services.

Wilson, B. A., Alderman, N., Burgess, P., Emslie, H., & Evans, J. J. (1996). *Behavioural Assessment of the Dysexecutive Syndrome (BADS)*. Bury St. Edmunds, England: Thames Valley Test Company.

Wilson, B. A., Cockburn, J., & Baddeley, A. D. (1985). *The Rivermead Behavioural Memory Test Manual*. Bury St. Edmunds, England: Thames Valley Test Company.

Yalon-Chamovitz, S., & Weiss, P. L. T. (2008). Virtual reality as a leisure activity for young adults with physical and intellectual disabilities. *Research in Developmental Disabilities, 29*(3), 273-287. doi: 10.1016/j.ridd.2007.05.004

Table 1

Comparison of means for the psychometric measures between the ADHD participants and healthy controls

	ADHD (n = 33)		Healthy controls (n = 42)			
Measures	*M*	*SD*	*M*	*SD*	*t*	*d*
Raven IQ	89.42	13.64	110	9.86	-7.32*	-1.76
d2						
Commission	30.48	28.26	10.92	12.95	3.68**	0.92
Omission	39.12	45.63	18.90	22.95	2.32*	0.58
Total correct	79.60	24.61	107.61	28.23	-4.50**	-1.04
WISC-IV						
WM	76.57	12.67	101.11	15.04	-7.50**	-1.74
PS	89.90	15.94	113.59	9.64	-7.52**	-1.85
Computer operation knowledge	16.39	2.90	16.04	3.39	0.46	0.10
Daily computer usage	1.84	0.56	1.92	0.34	-0.71	-0.17
Weekly computer usage	2.15	0.44	2.07	0.40	0.81	0.19

Note. WM = Working Memory; PS = Processing Speed, **$p < .01$; *$p < .05$

Table 2

Comparison of means for ClinicaVR: Classroom-CPT and CPT measures between the ADHD participants and healthy controls

	ADHD (*n* = 33)		Healthy controls (*n* = 42)		
Measures	*M*	*SD*	*M*	*SD*	*d*
ClinicaVR: Classroom-CPT with distractors[a]					
Commissions	33.76	30.92	10.75	6.24	1.03
Omissions	19.47	7.63	9.20	5.32	1.56
Total correct	35.52	7.63	45.80	5.32	-1.56
Reaction time	0.49	0.12	0.44	0.10	0.45
CPT with distractors[b]					
Commissions	60.56	50.21	14.72	17.34	1.22
Omissions	19.87	11.07	8.40	10.36	1.06
Total correct	34.37	11.34	47.18	8.35	-1.28
Reaction time	0.25	0.05	0.30	0.01	-1.38
ClinicaVR: Classroom-CPT without distractors[c]					
Commissions	42.70	48.59	11.05	7.97	0.90
Omissions	14.70	9.12	9.90	7.18	0.58
Total correct	39.23	9.58	45.10	7.18	-0.69
Reaction time	0.51	0.13	0.43	0.09	0.71
CPT without distractors[d]					
Commissions	59.62	55.27	10.81	6.53	1.24
Omissions	16.68	9.23	6.40	9.13	1.11
Total correct	38.31	9.23	48.63	9.10	-1.12
Reaction time	0.30	0.15	0.30	0.00	0

Note. M = mean age (years); *SD* = Standard Deviation; [a] = Commission errors, Omission errors, Total correct, Reaction time measured in seconds with the ClinicaVR: Classroom-CPT with distractors – are raw scores; [b] = Commission errors, Omission errors, Total correct, Reaction time measured in seconds with the Continous Performance Test with distractors – are raw scores; [c] = Commission errors, Omission errors, Total correct, Reaction time measured in seconds with the ClinicaVR: Classroom-CPT without distractors – are raw scores; [d] = Commission errors, Omission errors, Total correct, Reaction time measured in seconds with the Continous Performance Test without distractors – are raw scores; *d* = Cohen's *d* effect size